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OVERVIEW OF SUBSONIC TRANSPORT PROPULSION TECHNOLOGY

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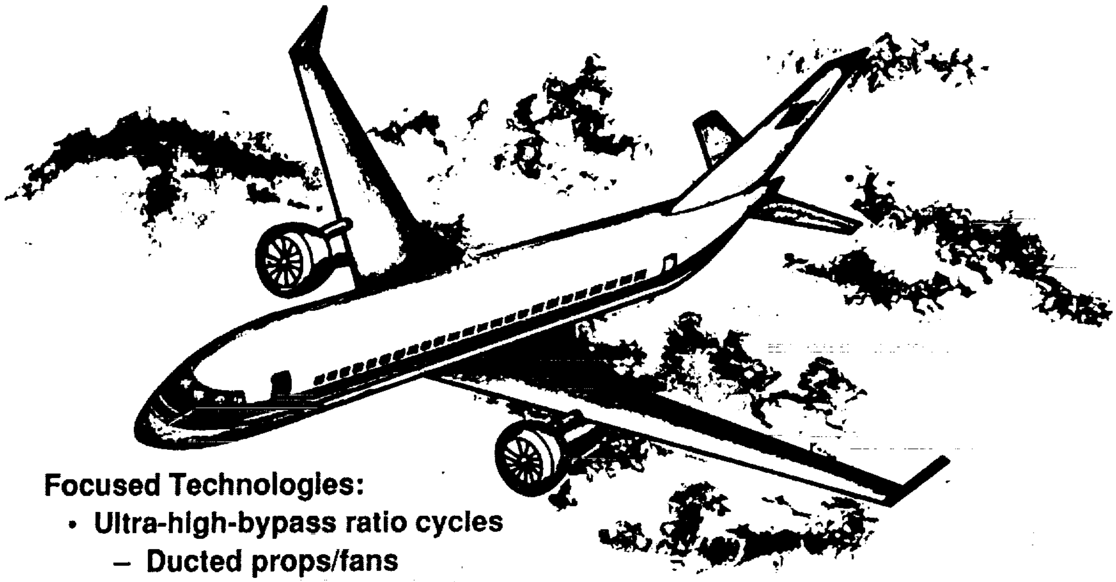
This overview summarizes the major elements of the NASA Lewis Research Center's subsonic transport propulsion research program. Ultra-high-bypass ratio cycles and high-efficiency cores are being investigated for propulsive and thermal efficiency improvements, respectively. Overall efficiency gains are sought subject to the constraints of noise and emissions goals. Elements of the research program including key technical issues are discussed along with the planned sequence of the activities.

Overview of Subsonic Transport Propulsion Research



Focused Technologies:
- **Ultra-high-bypass ratio cycles**
  - **Ducted props/fans**
  - **Unducted props**
- **High-efficiency core**

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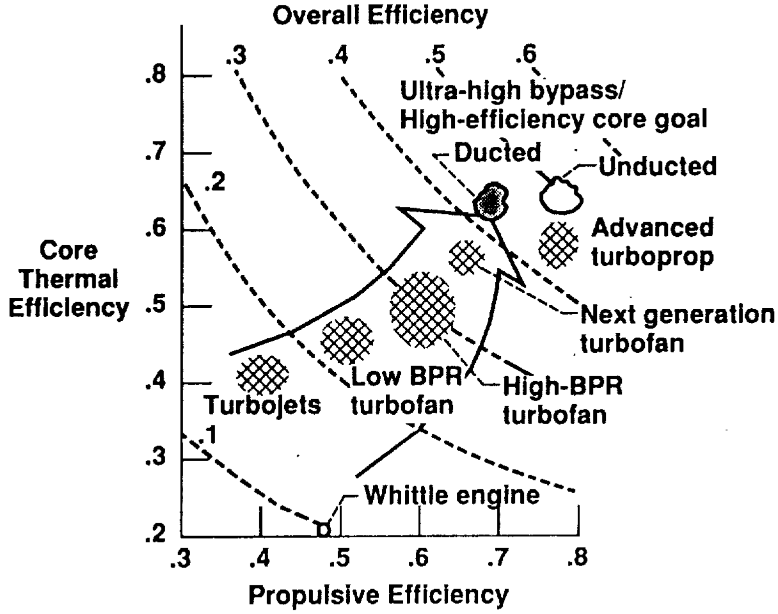
Propulsion technology for subsonic transports is focused in two main areas: (1) Ultra-high-bypass (UHB) ratio cycles and (2) high-efficiency cores. Previous work demonstrated the technology for fuel-efficient, unducted, advanced turboprops and that effort is concluding. Unducted ultra-high-bypass ratio engines are subject to total thrust limits due to diameter constraints for under-the-wing installations. Thus, current work emphasizes ducted prop/fan configurations suitable for large wide-body aircraft powered by two large-thrust engines mounted under the wing. High-efficiency core investigations center around increasing thermal efficiency by pushing core pressure ratios and temperatures higher. The overall goal is to maximize engine efficiency subject to the environmental constraints of aircraft noise rules and emission limits.

Subsonic Propulsion Efficiencies



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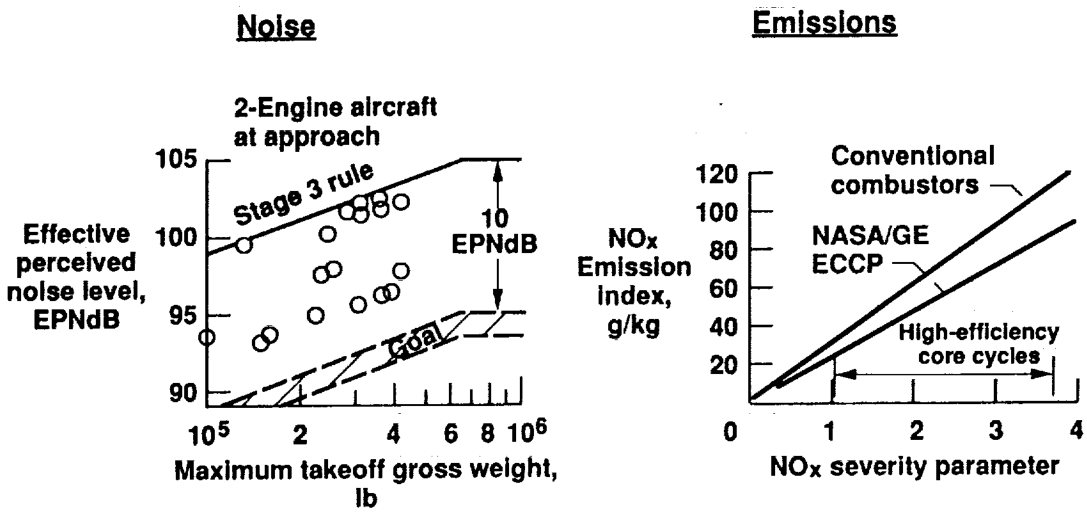
The contributions of low spool propulsive efficiency and core thermal efficiency to overall propulsion efficiency are shown in this figure. The historic progression is from the first generation turbojets to low-bypass turbofans to current high-bypass turbofans. Advanced turboprop technology represents a major increase in propulsive efficiency. The subsonic goal is to develop the core and low-spool technology to reach the overall efficiency targets shown. In the unducted case, the goal is obtainable through core thermal efficiency gains combined with demonstrated advanced turboprop propulsive efficiencies. However, in the ducted case, new low-pressure spool technology is required in addition to the core improvements.

Subsonic Transport Environmental Constraints



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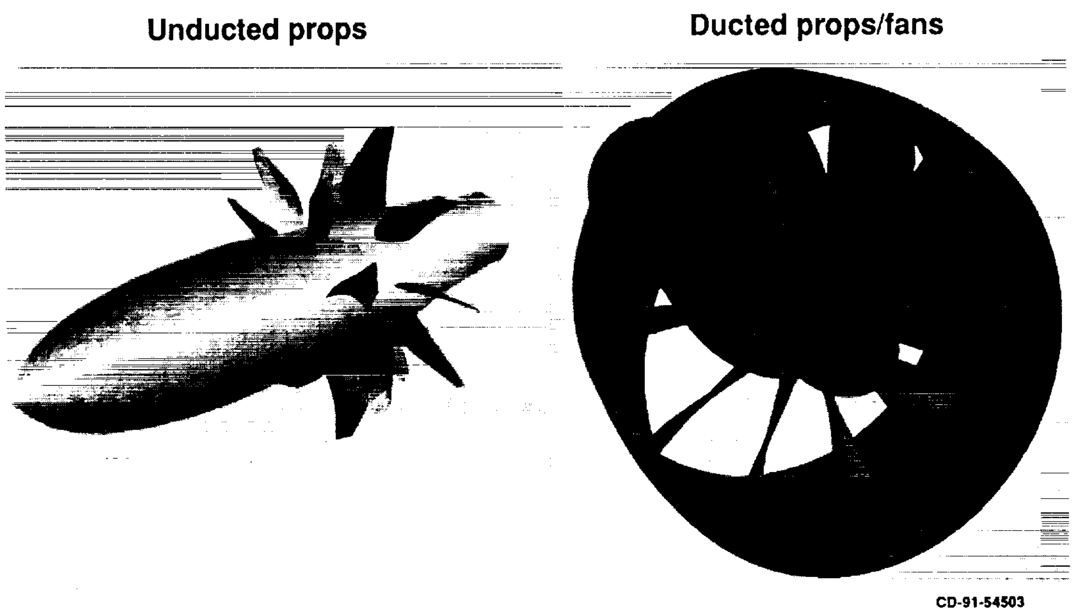
Two environmental constraints which must be satisfied while the efficiency gains are pursued are noise and emissions. Currently, new aircraft must meet the FAR 36, Stage 3 noise rules. The example shown for two-engine aircraft at approach shows that certified effective perceived noise levels (EPNL) for the newest aircraft are already lower than those required for the maximum takeoff gross weights between 100 000 and 400 000 pounds. Part of the reason they are quieter is that the current operating environment is constrained by local airport noise rules which are considerably more stringent than FAR 36, Stage 3. Aircraft noise also poses a significant constraint on the capacity of the air transport system by limiting the hours of operation and airport expansion. Thus, a noise goal for new ultra-high-bypass technology of FAR 36, Stage 3 minus 10 EPNdB has been chosen by NASA for technology development. A band is shown to reflect the fact that a 2 to 3 EPNdB margin must be built in to reduce certification risk. Of course, the goal must be obtained at the takeoff and sideline points, also, and at higher takeoff gross weights.

Emission constraints are not as well defined. Emission index (EI) in grams of NO_x per kilogram of fuel burned is plotted against a NO_x severity parameter which is a function of combustor temperature and pressure. The trends for conventional combustors and the more advanced technology developed under the NASA/GE Experimental Clean Combustor Program (ECCP) are shown. High-efficiency core technology utilizing higher pressures and temperatures will increase the NO_x severity parameter significantly, as indicated by the range labeled on the abscissa for the cycle parameters being studied. Therefore, while specific numerical goals have not been set at present, there is clearly the technical challenge to develop low-NO_x combustors as part of high-efficiency core technology.

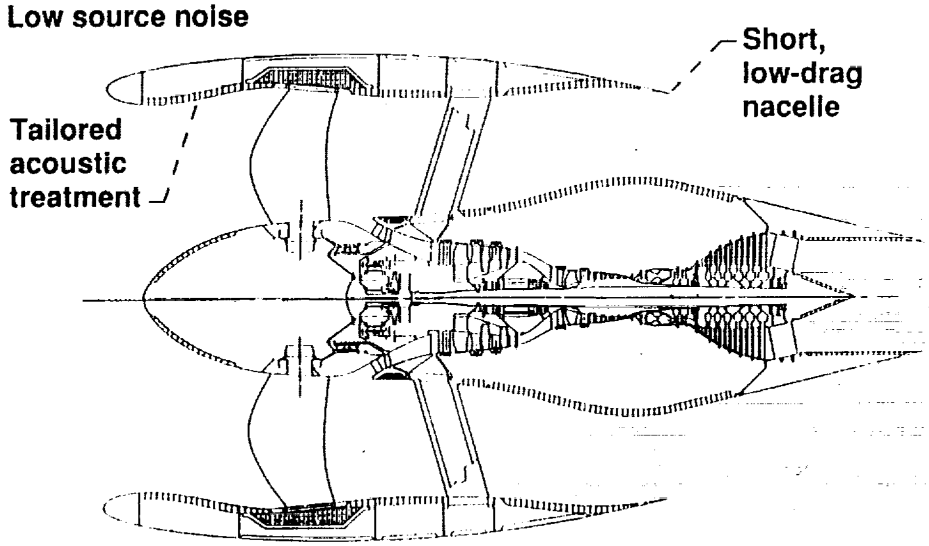
Ultra-High Bypass



The two subdivisions of ultra-high-bypass technology, unducted and ducted props/fans, are shown pictorially as a counterrotation configuration with combined forward and aft swept rotors and a single wide-chord swept rotor in a very short duct. Although the first generation of *aft-swept* advanced turboprop technology is in hand, *forward* sweep is being investigated as part of the conclusion of unducted research. Aerodynamic and acoustic aspects of this work are expected to carry over to a comprehensive investigation of ducted rotors with either forward or aft sweep. The ducted picture comes from computational work to analyze in one integrated computational fluid dynamics (CFD) calculation both the internal and external flow fields. Because the duct is short and thin to minimize weight and cruise drag, not only integrated aerodynamic but also an integrated aeroacoustic analysis will probably be required to capture the performance and noise characteristics of these propulsors.

Ducted Ultra-High Bypass

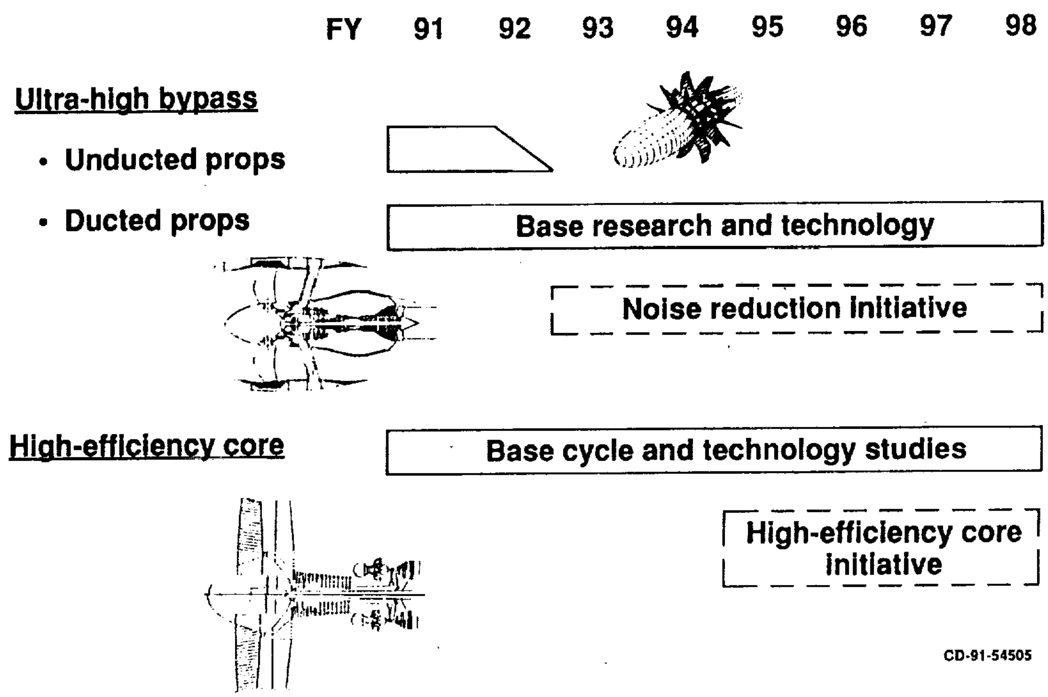
(Ratios, Bypass 10 to 20+)



Technical Issues
- Geared vs ungeared rotor drives
- Variable vs fixed pitch rotors

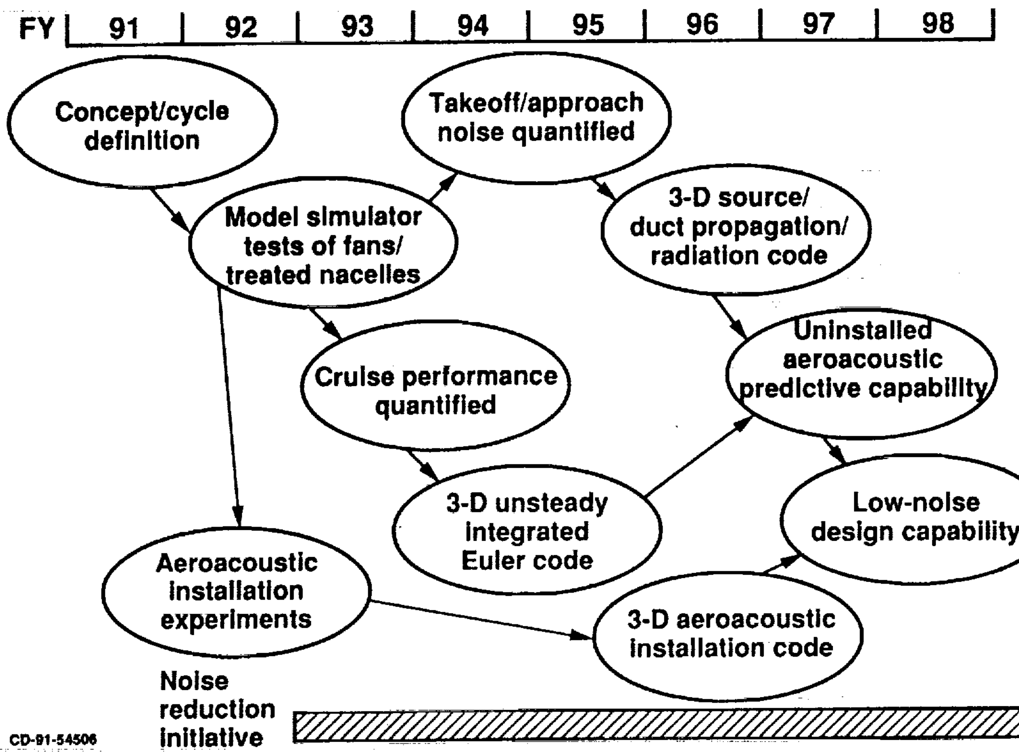
Some features and technology issues associated with ducted ultra-high-bypass propulsors are shown here. The rotor is expected to have fewer blades with wider chords than current turbofans. Bypass ratios greater than 10 and perhaps as high as 20 or more are under consideration. Geared versus ungeared rotor drives and variable-versus fixed-pitch rotors are under consideration. Such choices will be based on the outcome of noise-constrained cycle studies and mission analyses now underway. The short, low-drag nacelle (having a total length perhaps of the order of one rotor diameter) poses particular acoustic problems. Low rotor source noise is a very high priority since space for acoustic treatment is severely limited. Acoustic treatment designs must be highly tailored to and integrated with the prop/fan aeroacoustic design. Rotor stall margin and distortion tolerance must be addressed for prop/fan design parameters and off-design operating conditions not experienced by current turbofans.

Subsonic Transport Aeropropulsion Program



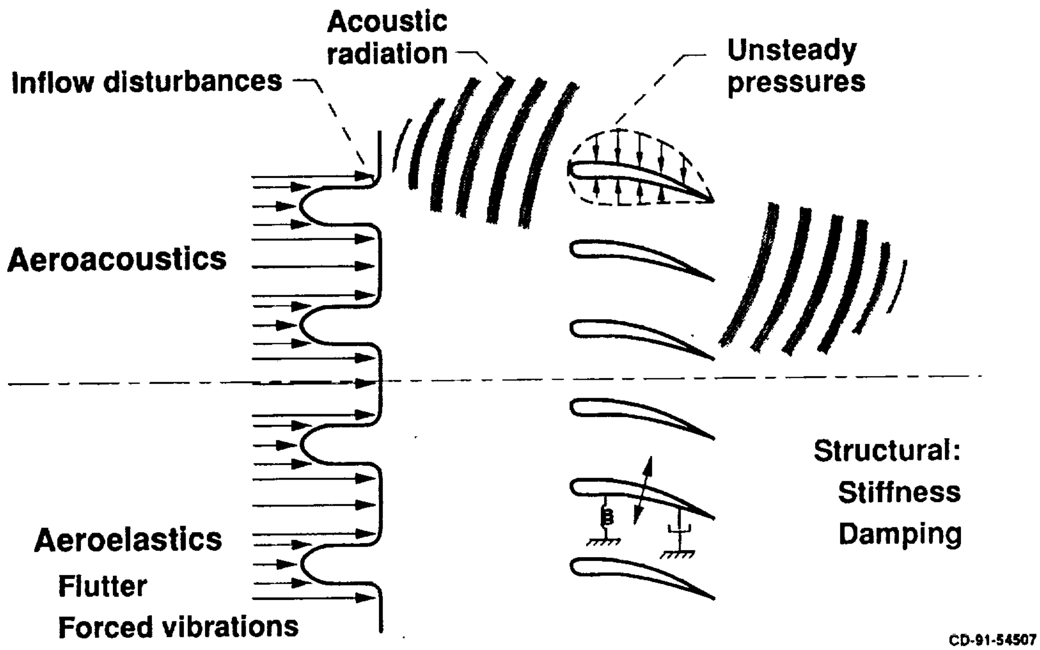
The elements of the overall NASA program in aeropropulsion research for subsonic transports are shown along with the planned sequence. Unducted ultra-high-bypass work is winding down with the effort expected to be essentially complete by the end of FY '92. On the other hand, the base research and technology program in ducted props/fans is well established and growing with a multiyear effort planned. In addition, a noise reduction initiative has been planned for a possible FY '93 start. That effort would draw on the base aerodynamic and source noise reduction technology to arrive at a total design-for-noise capability. An experimental validation using a large powered transport model incorporating high lift and installation aerodynamics technologies with the source noise reduction element would be the program endpoint. Parallel to the ultra-high-bypass propulsor technology is the high-efficiency core research effort. A base program is underway with cycle and technology definition studies nearing completion in preparation for a sustained base technology effort. The intent is to support a high-efficiency core initiative in the FY '95 time period.

Ducted Prop/Fan Base Research Program



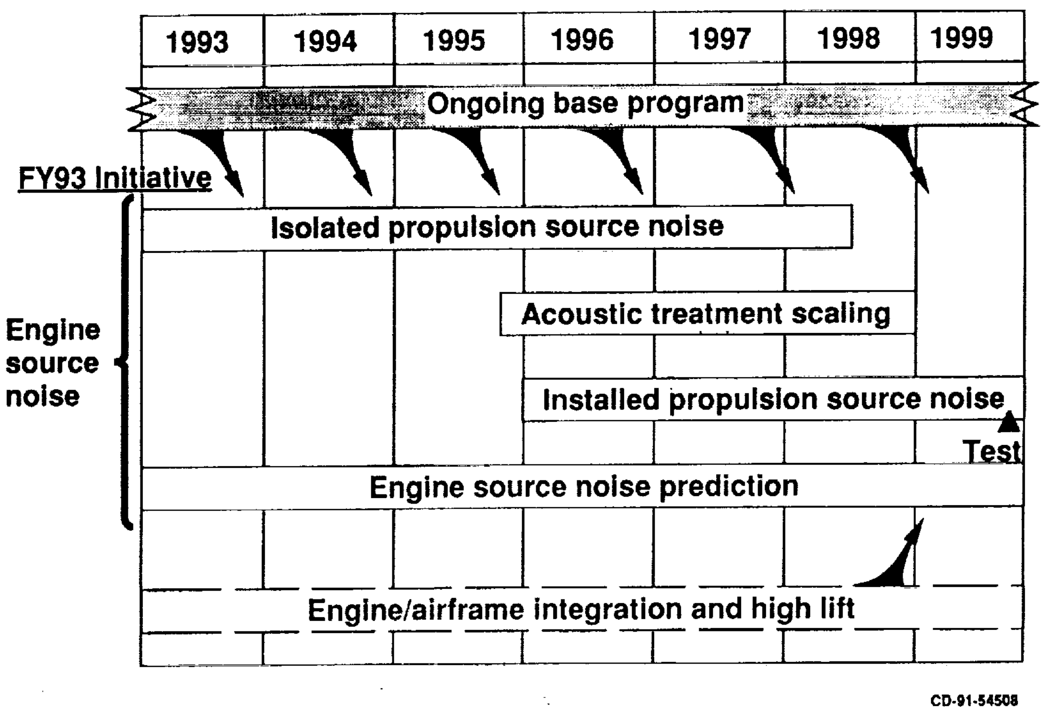
The relations between the main functional elements of the ducted prop/fan research program are shown along with the rough time sequence of the activity. Concept and cycle definition studies are translated into model simulator hardware for wind tunnel tests. Low speed tests quantify takeoff and approach noise and off-design aerodynamic performance. Three-dimensional codes for noise source/propagation/radiation predictions are validated using the wind tunnel data. High-speed tests quantify cruise aerodynamic performance and furnish the data to validate three-dimensional steady and unsteady integrated Euler and Navier-Stokes codes. The low- and high-speed work comes together to provide an uninstalled aeroacoustic prediction capability. Another parallel path of research activity addresses aeroacoustic installation effects both experimentally and computationally. When the uninstalled and installed results are brought together, the ultimate goal of a low-noise, high-efficiency design capability for ducted ultra-high-bypass propulsors is realized. In actuality, the process just outlined, with the exception of cycle definition, may be iterated several times during the 8-year period shown. This base technology will support the planned Advanced Subsonic Transport Noise Reduction Initiative which is planned for FY '93.

Unsteady Aerodynamics Research for Subsonic Propulsion



Unsteady aerodynamics is a key area of research encompassing both the aeroacoustic and aeroelastic elements of subsonic propulsion technology. On the aeroacoustic side, inflow disturbances interacting with blade rows produce unsteady blade pressures, which couple with the duct geometry to determine the sound radiated. On the aeroelastic side, flow disturbances drive blade-forced vibrations or couple with blade motions to produce flutter depending on the stiffness and damping characteristics of the blade row. Thus, the understanding and modeling of the unsteady interactions of blade rows with flows is essential to the ability to design for low noise and structural integrity. For these reasons the ducted prop/fan base research program contains considerable work on blade row unsteady aerodynamics.

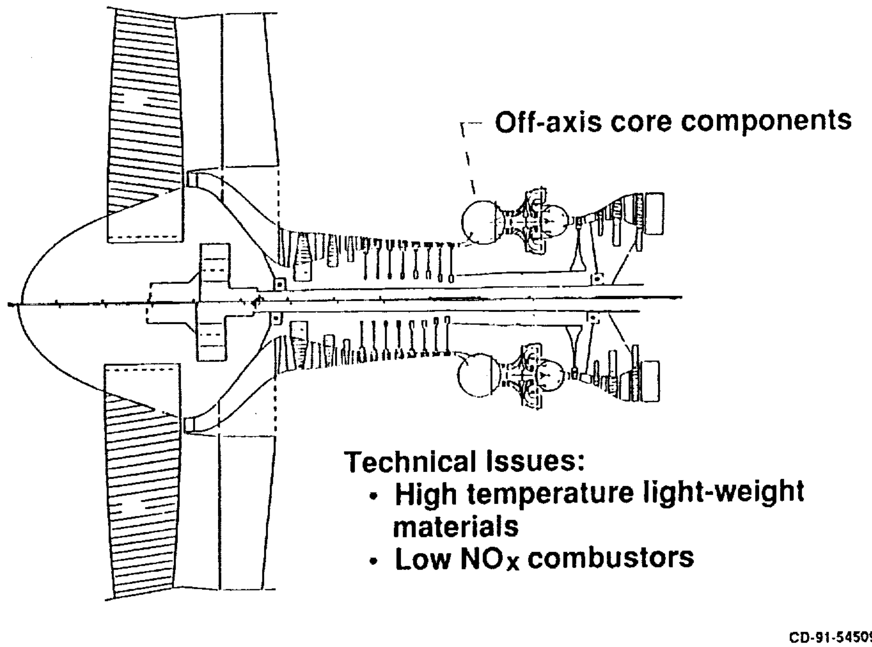
Advanced Subsonic Noise Reduction Initiative



Elements of the engine source noise portion of the planned FY '93 Advanced Subsonic Noise Reduction Initiative are shown. Isolated source noise reduction work will focus on experiments using integrated fan/treated nacelle simulators. Acoustic treatment scaling work will establish scaling methodology by a combination of simulator and full-scale engine experiments. Installed propulsion source noise efforts will culminate in the aeroacoustic test of a large airplane model with propulsion simulators in the NASA Ames 40 x 80 Wind Tunnel. Accompanying these three efforts is the development and validation of engine source noise prediction methodology subject to the constraints of efficiency and structural integrity. Two other elements of the total noise reduction initiative planned (engine/airframe integration and high lift systems) determine the configuration of the airplane model and the way the simulators are installed on it. The ongoing base program supplies technical concepts and tools for use in the highly focused noise reduction initiative.

High-Efficiency Core

(Overall pressure ratio, 50 to 100; combustor inlet temperature, >1000 °F)



Some features and technology issues associated with high-thermal-efficiency cores are shown. Overall pressure ratios being investigated range from 50 to 100, and combustor inlet temperatures are greater than 1000 °F. High-temperature, lightweight materials with minimal cooling requirements are needed along with combustor designs to limit NO_x, in spite of the high temperatures and pressures. In such a compression system at high pressure ratios, conventional compressor design approaches lead to very small flow path and blade heights. Consequently, the usual problems in attaining high component efficiencies in small turbomachinery are multiplied, and unconventional geometries such as off-axis core modules are being studied. For example, each module might contain a centrifugal compressor, combustor, and radial turbine; and there may be several of these modules spaced circumferentially around the engine axis.

CONCLUDING REMARKS

In the subsonic propulsion research area, noise reduction is emerging as a dominant theme as a means to alleviate noise constraints on the capacity of the air transport system. The impact is greatest on the design of the low-pressure (prop/fan) portion of the engine because the dominant noise source is the rotor. Since a large body of technology was developed for unducted rotors over the last decade and application of that technology to commercial products has been delayed by market forces, current research emphasis is on technology for ducted configurations suitable for new twin-engined, long-range aircraft. A parallel effort to develop high thermal efficiency cores is about to move into base technology work now that cycle studies have identified the technology issues and concepts to address them.

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